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Report No. 216

From Project No. 6-95-20-001

# THE JUDGMENT OF ANGULAR POSITIONS IN THE HORIZONTAL PLANE ON THE BASIS OF KINESTHETIC CUES

by

L. S. Caldwell and M. J. Herbert

from

Psychology Department

Submitted

18 October 1955

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Abstract;

It was found that adjustive movements of the arm in the horizontal plane are most accurate near the 0° and 90° positions. The 0° position is directly in front of the right shoulder and the 90° position is 90° clockwise from this point. Adjustive movements of the arm toward the 90° end of the scale are more accurate than those toward 0°.



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REPORT NO. 216

# THE JUDGMENT OF ANGULAR POSITIONS IN THE HORIZONTAL PLANE ON THE BASIS OF KINESTHETIC CUES*

by

L. S. Caldwell and M. J. Herbert

from

Psychology Department
ARMY MEDICAL RESEARCH LABORATORY
FORT KNOX, KENTUCKY

*Subtask under Psychophysiological Studies, AMRL Project No. 6-95-20-001, Subtask, Control Coordination Problems.

Report No. 216
Project No. 6-95-20-001
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MEDEA


## ABSTRACT

### THE JUDGMENT OF ANGULAR POSITIONS IN THE HORIZONTAL PLANE ON THE BASIS OF KINESTHETIC CUES

#### OBJECT

To determine, on the basis of kinesthetic cues, the relative accuracy with which the angular positions from 0° to 90° in the horizontal plane could be located when the starting position of the arm varied from trial to trial and an equal amount of information was given about the location of each position on the scale.

#### RESULTS

It was found that the angles at the extremes of the scale (0° and 90°) were most accurately located. There was a slight indication of increased accuracy near the midpoint of the scale. When the primary adjustive movement was toward the larger angular values on the scale (ascending) the smaller angles tended to be overestimated, and the larger angles underestimated. When the primary adjustment was toward the smaller angular values (descending), there was a general tendency to underestimate all angles. Performance was more accurate for the ascending condition than for the descending. With practice, there was a decrease both in the constant errors and the variable errors, but the latter only was significant.

#### CONCLUSIONS

The results tend to support the hypothesis that the greatest accuracy of angular estimations is found in the regions in which the kinesthetic cues are greatest - that is, where the subjects reported the greatest resistance to maintaining the arm position. Also, the results suggest that the accuracy of angular estimations is greater when moving a control against an opposing force than when moving it with an aiding force.

## RECOMMENDATIONS

Recommendations useful to the design engineer which follow from the results obtained in this investigation are: 1) a control can be most accurately located in the horizontal plane when it is positioned near the $0^{\circ}$ and $90^{\circ}$ positions (in front of the right shoulder or $90^{\circ}$ clockwise from this position); 2) a control can be more accurately positioned in the horizontal plane when it is moved toward $90^{\circ}$ than when it is moved toward $0^{\circ}$.

Submitted 18 October 1955 by:

L. S. Caldwell, Psychophysiologist
M. J. Herbert, Psychophysiologist

APPROVED: Ray G. Daggs
RAY G. DAGGS
Director of Research

APPROVED: William W. Cox
WILLIAM W. COX
Lt Colonel, MC
Commanding

THE JUDGMENT OF ANGULAR POSITIONS IN THE HORIZONTAL PLANE ON THE BASIS OF KINESTHETIC CUES

## I. INTRODUCTION

The present investigation represents the first of a series of proposed studies on the role of kinesthesis (in conjunction with other sensory systems) in the estimation of control positions. Several studies have been reported in this area but still there is a notable lack of data from which to draw general principles. The number of variables affecting the apparently simple task of estimating the position of a control is so great that an extensive research program is indicated. For example, the accuracy of estimating a particular position may be a function of the experimental method used, the distance between the goal position and the starting point of the movement, the direction of the primary adjustive movement, the relationship between this position and the anchor points, the quantity and sensory modality of the information given the subject, etc.

It has been reported that subjects can estimate angular positions of $0^{o}$ and $90^{o}$ with considerable accuracy without the use of visual cues. It is not clear, however, whether this is due to the fact that the subjective scale coincides with the objective scale in these regions or whether this accuracy is a product of the particular method of measurement employed. In most studies on the accuracy of estimating the angular positions of a control, a control is centered at $0^{o}$ and all movements are made from this position. Thus, the subjects are given more information about the location of $0^{o}$ than any other point on the scale. This procedure may well account for the almost phenomenal accuracy of estimating angles near $0^{o}$. Another approach would be to have each angular position estimated from every other position on the scale employed. Such a procedure would equalize information over the full scale and thus give a less biased estimate of the accuracy of judgments of the positions at and near $0^{o}$. While the former method is comparable to a situation in which a zero-centering control is employed, the latter is more like one in which the control is not spring-loaded and the movements do not have a constant starting point.

The present study started with the question: "How accurately can a person point out the various angular positions in the horizontal plane when the starting position of his arm varies from trial to trial, if an equal amount of information is given about the location of each position on the scale"?

## II. APPARATUS, SUBJECTS AND PROCEDURE

### A. Apparatus

The apparatus shown in Figure 1 consists of a well-padded sleeve suspended from an arm connected to a freely moving vertical

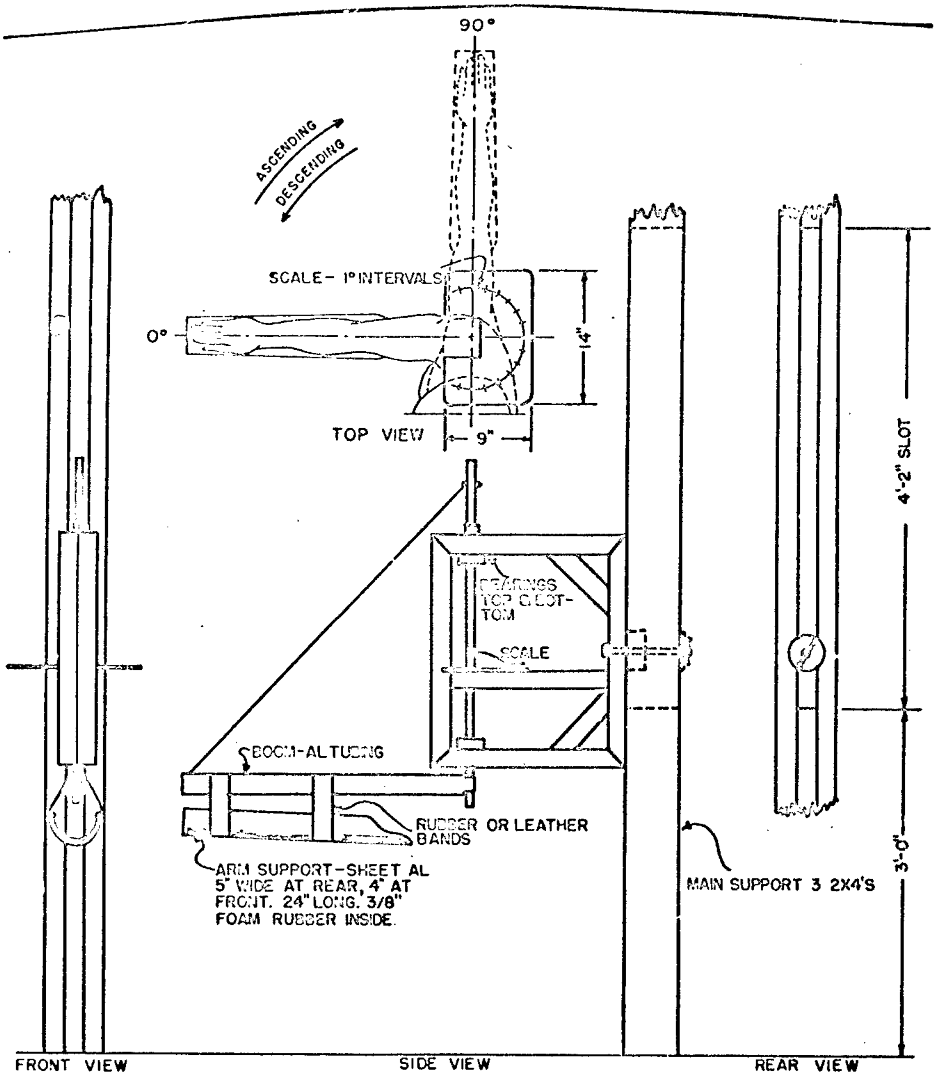


FIG I. ARM KINESTHESIOMETER

shaft. A pointer connected to the shaft rides over a plate on which an angular scale divided into $1^{\circ}$ intervals is etched. The apparatus can be raised or lowered to adapt to the subject's trunk length. This apparatus represents a compromise between a situation in which a subject can merely point to the various angular positions in the horizontal plane and one which provides a ready and accurate indication of the horizontal position of the arm.

B. Subjects and Procedure

The 6 subjects employed in the present investigation were selected on the basis of long-term availability and the lack of previous experience in any experiment which directly involved the estimation of angular positions. Since the two experimenters served as subjects in the study and, thereby, were aware of the performance of all the subjects, knowledge of results was equalized over all subjects by keeping them fully informed at all times about their own performance and the performance of others. Also, this procedure was used as a means of fostering intersubject and intrasubject competition so that interest in this simple task would be maintained during the full course of the study. This last point is important because, in a similar study (1) in which a great number of trials were given the subjects and they were not informed of the results, the constant errors for the second half of the trials were significantly greater than for the first half. This increase in error possibly resulted from loss of interest in the task.

At the beginning of the first session each subject was seated so that the shoulder joint of his right arm was directly beneath the vertical shaft. The apparatus was then positioned so that the end of the shaft barely cleared his shoulder. The vertical position of the apparatus and the chair position were marked for each subject. These positions were employed in all further sessions. Then the subject was told to move his arm left and right and report if he obtained any cues from the operation of the apparatus. If such cues were reported, this was corrected by slight adjustments of the chair or sleeve. The subjects removed their shirts before each experimental session.

The subject was blindfoled and instructed to imagine that he was seated in the center of a horizontal clock-face, so numbered that when his arm was pointing directly forward (to the 12 o'clock position) the scale reading was $0^{\circ}$, and when his arm was at the 3 o'clock position the scale reading was $90^{\circ}$. The subject was told that his arm would be set by the experimenter to various positions on this scale and that his task was to move his arm to the angular positions indicated by the experimenter. He was informed that the scale ranged from 10° to the left of zero (-10°) to 100° to the right of zero. (The -10° and 100° positions were used to permit movements in both directions to the 0° and 90° positions. The -10° and 100° positions were not treated in the analysis of the data.) For each trial, the subject was informed of the starting position of his arm and the position at which he brought his arm to rest.

The starting points and goal points were so paired that each angle was estimated an equal number of times from every other position on the scale. For example, 30° was estimated from -10°, 0°, 10°, 20°, 40°, 50°, etc. It should be noted that on some trials the movement of the arm was toward the higher angular values on the scale, and on others the movement was toward the lower values. The 144 combinations of starting points and goal points were selected at random and assigned to 4 blocks of trials. The complete series of 144 trials (4 blocks of 36 trials each) is referred to as a "set of trials." The blocks of trials were so constructed that each angle from -10° to 100° was a starting point 3 times and a goal point 3 times. Each block consisted of 36 trials. One block of trials was given each morning and afternoon for 16 days. The blocks were given in an unbiased order.

## III. RESULTS

There are two measures of the accuracy with which a subject estimated the various angular positions: the constant error, and the variable error. The constant error (C.E.) is obtained by algebraically summing the errors and dividing by the number of observations. Thus the C.E. shows both the direction and mean extent of the error. The standard deviation (S.D.) is used as the measure of the variability of the estimates of each angle. That is, the S.D. indicates the dispersion of the estimates about the C.E.

The main results of this study are given in Tables 1 and 2. The C.E.s are presented in Table 1 and the S.D.s are given in Table 2. In both tables the means for the first and second halves of the trials and for the total trials are given for each angular position. The entries in column 8 are not the means of the entries in columns 3 and 6 because there was not an equal number of ascending and descending trials. There was a predominance of descending trials to the small angles and a predominance of ascending trials to the larger angles. The term "ascending" refers to an adjustment in which the primary movement is toward the 90° end of the scale, and the term "descending" refers to a movement toward the 0° end.

TABLE 1

MEAN CONSTANT ERRORS IN DEGREES OF ARC FOR THE FIRST AND SECOND HALVES OF THE ASCENDING AND DESCENDING TRIALS AND FOR TOTAL TRIALS. FROM THE ESTIMATION OF ANGLES 0° THROUGH 90° BY ARM MOVEMENTS IN THE HORIZONTAL PLANE

| | Ascending Trials | | | Descending Trials | | | |
|---|---|---|---|---|---|---|---|
| Angle Estimated | First Half | Second Half | Total Ascending | First Half | Second Half | Total Descending | Total Trials |
| 0° | 2.2 | 2.3 | 2.3 | -0.5 | 0.7 | 0.1 | 0.5 |
| 10° | 0.7 | 2.1 | 1.4 | -2.4 | -1.1 | -1.8 | -1.3 |
| 20° | 0.2 | 0.8 | 0.5 | -3.6 | -2.6 | -3.1 | -2.1 |
| 30° | 0.8 | 1.3 | 1.1 | -4.4 | -2.9 | -3.6 | -2.1 |
| 40° | 0.3 | 0.6 | 0.4 | -4.3 | -3.7 | -4.0 | -1.9 |
| 50° | 1.4 | 1.7 | 1.6 | -3.9 | -2.6 | -3.3 | -0.4 |
| 60° | -1.5 | -2.6 | -2.0 | -4.4 | -1.7 | -3.0 | -2.4 |
| 70° | -2.5 | -2.3 | -2.4 | -4.3 | -3.7 | -4.0 | -2.9 |
| 80° | -1.6 | -1.5 | -1.6 | -5.6 | -5.4 | -5.5 | -2.3 |
| 90° | -1.4 | -1.7 | -1.5 | -3.8 | -2.6 | -3.2 | -1.7 |

TABLE 2

MEAN VARIABLE ERRORS IN DEGREES OF ARC FOR THE FIRST AND SECOND HALVES OF THE ASCENDING AND DESCENDING TRIALS AND FOR TOTAL TRIALS. FROM THE ESTIMATION OF ANGLES 0° THROUGH 90° BY ARM MOVEMENTS IN THE HORIZONTAL PLANE

| | Ascending Trials | | | Descending Trials | | | |
|---|---|---|---|---|---|---|---|
| Angle Estimated | First Half | Second Half | Total Ascending | First Half | Second Half | Total Descending | Total Trials |
| 0° | 1.8 | 1.8 | 2.0 | 3.5 | 3.9 | 3.7 | 3.5 |
| 10° | 2.7 | 2.6 | 2.8 | 4.8 | 4.1 | 4.8 | 4.1 |
| 20° | 4.1 | 3.3 | 3.8 | 5.0 | 4.5 | 4.9 | 4.9 |
| 30° | 3.9 | 4.8 | 4.7 | 6.3 | 5.2 | 5.8 | 6.0 |
| 40° | 3.7 | 4.1 | 4.0 | 6.4 | 5.1 | 5.9 | 5.6 |
| 50° | 5.4 | 5.3 | 5.6 | 5.4 | 5.7 | 5.7 | 6.2 |
| 60° | 4.8 | 4.8 | 4.9 | 4.2 | 4.1 | 4.7 | 4.9 |
| 70° | 5.5 | 5.1 | 5.4 | 4.3 | 4.1 | 4.2 | 4.7 |
| 80° | 5.4 | 4.8 | 5.1 | 4.2 | 4.1 | 4.3 | 5.3 |
| 90° | 4.4 | 4.1 | 4.4 | 2.6 | 2.0 | 2.8 | 4.1 |

The main factor considered in the present study was the relative accuracy with which the subjects estimated the various angular positions. Of secondary interest was the influence of the direction of the primary adjustive movement on the accuracy of the estimation. In addition, the effects of practice on the various aspects of the performance were analyzed in some detail. The latter analysis was necessitated by the fact that repeated measurements were made on the subjects and each subject received complete knowledge of the accuracy of his performance.

The results are presented in 3 sections: (A) the relative accuracy of estimating the various angular positions; (B) the influence of the direction of the primary movement on the accuracy of the judgments; and (C) the effects of practice on the accuracy of performance.

A. Accuracy of Estimating the Various Angular Positions

As shown in column 8 of Table 1 and in Figure 2 the smallest constant errors were obtained at the ends and near the midpoint of the scale. The 4 smallest constant errors were at 0°, 10°, 50°, and 90°. The accuracy of estimation was considerably better at 0° than at 90°. The C. E. s ranged from -0.4° to -2.9°. The mean C. E. for all angles was -1.7°. The only positive C. E. was obtained at 0°. As reported in somewhat similar studies (1, 2), the greatest errors were found in the regions midway between the ends and midpoint of the scale. As shown in Figure 2, the regions of least accuracy are from 20° to 40°, and 60° to 80°.

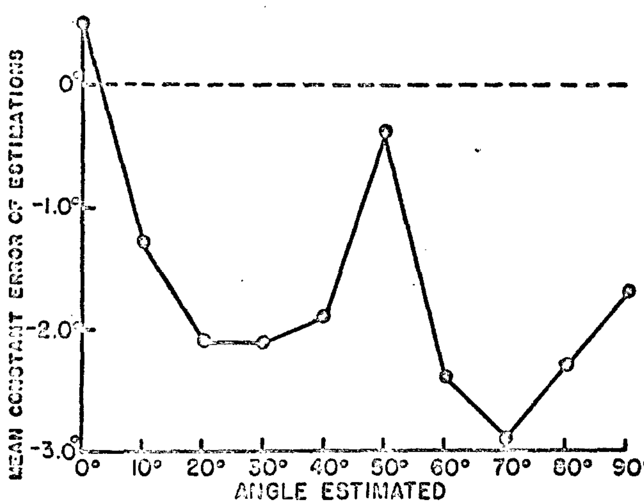


FIG. 2. MEAN CONSTANT ERRORS OF ESTIMATIONS OF ANGLES 0° THROUGH 90° BY ARM MOVEMENTS IN THE HORIZONTAL PLANE.

The analysis of variance of the data for the estimation of angles is shown in Table 3. There is no F-ratio for Between Subjects as the experimental design employed does not yield an appropriate error term for the evaluation of this variable. The error term for Sets of Trials is the Subjects x Sessions interaction and the error term for Angles is the Subjects x Angles interaction. The second-order interaction (SxAxB) is the error term for the 3 simple interactions. The primary results of this analysis were as follows: 1) no significant practice effect, as shown by the non-significant F for Sessions; 2) significant difference ($P = .01$) in the accuracy with which the angles were estimated. The simple interactions are not important.

TABLE 3
ANALYSIS OF VARIANCE OF DATA ON THE ESTIMATION OF ANGLES $0^{\circ}$ THROUGH $90^{\circ}$ BY ARM MOVEMENTS IN THE HORIZONTAL PLANE

| Source of Variation | Sum of Squares | df | Mean Square | F |
|---|---|---|---|---|
| Between Subjects (S) | 1662.7 | 5 | 332.54 | --- |
| Between Sets of Trials (A) | 114.8 | 7 | 16.40 | 2.23 |
| Between Angles (B) | 440.4 | 9 | 48.93 | 3.35** |
| Interaction: S x A | 256.9 | 35 | 7.34 | 3.31** |
| Interaction: S x B | 657.5 | 45 | 14.61 | 6.58** |
| Interaction: A x B | 182.9 | 63 | 2.90 | 1.31 |
| Interaction: S x A x B | 700.00 | 315 | 2.22 | --- |
| Total | 4015.2 | 479 | | |

**p = .01

The variable errors shown in Figure 3 and column 8 of Table 2 present another aspect of the accuracy of estimating the various angles. Again, it was found that the smallest errors occurred at $0^{\circ}$ and $90^{\circ}$, with the standard deviation at $0^{\circ}$ being the smallest. Contrary to the previous analysis, there was no reduction of error near the midpoint of the scale. In fact, the greatest variability in estimates was at the $50^{\circ}$ position. The mean variable errors ranged from $3.5\sigma$ at $0^{\circ}$ to $6.2\ \sigma$ at $50^{\circ}$, with a mean for all angles of $4.9\ \sigma$. Taking both the constant errors and variable errors into consideration, it was found that the angular estimations were best at the extremes of the scale, with only a slight indication of increased accuracy at the midpoint of the scale.

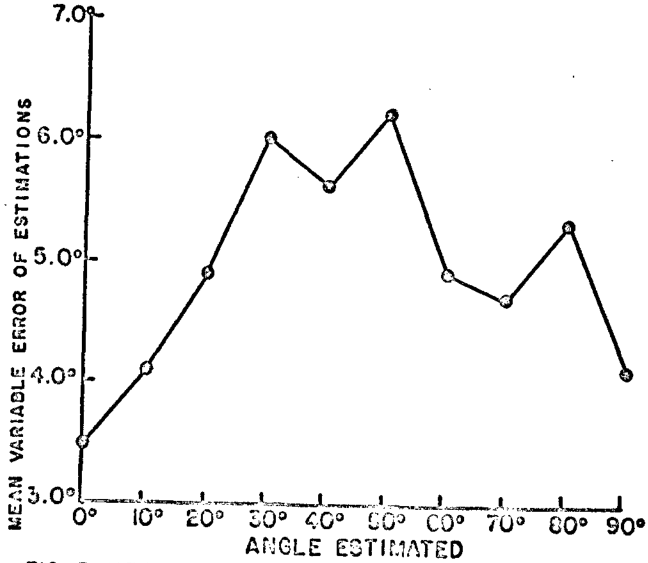


FIG. 3. MEAN VARIABLE ERRORS OF ESTIMATIONS OF ANGLES 0° THROUGH 90° BY ARM MOVEMENTS IN THE HORIZONTAL PLANE.

B. Influence of the Direction of the Primary Adjustive Movement on the Accuracy of Estimating the Various Angular Positions

An examination of Figure 4 reveals that when the arm is moved toward the $0^{o}$ end of the scale (descending) all angles from $0^{o}$ to $90^{o}$ were subjectively smaller than when the arm was moved toward the $90^{o}$ end of the scale (ascending). At all positions except $0^{o}$ the errors on the descending trials were greater than those on the ascending trials. A statistical sign test of the 10 pairs of mean C. E. s for the ascending and descending trials demonstrated a difference between the 2 conditions which was significant at the 2% level of confidence. The mean difference between the C. Es for these conditions was approximately $3^{o}$.

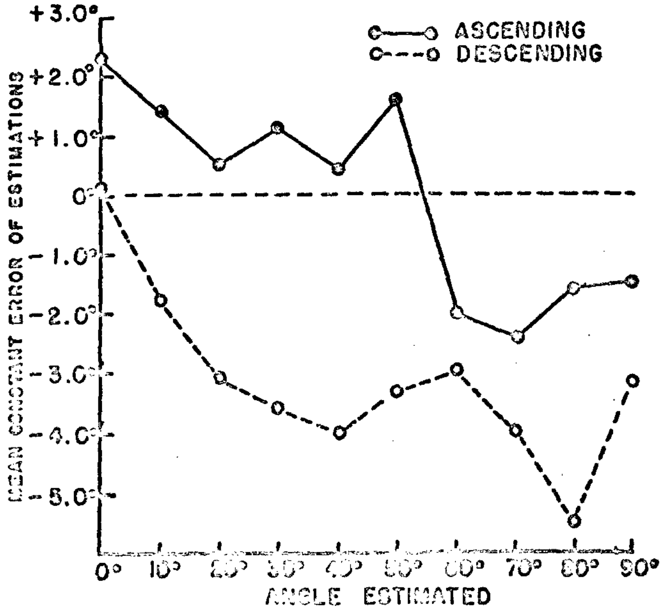


FIG. 4. MEAN CONSTANT ERRORS OF ESTIMATIONS FOR THE ASCENDING AND DESCENDING CONDITIONS OF ANGLES 0° THROUGH 90° BY ARM MOVEMENTS IN THE HORIZONTAL PLANE.

The various statistical sign tests referred to in the subsequent material are presented in Table 4.

As shown in Figure 4 and columns 4 and 7 of Table 1, all errors in the ascending condition for the angles from $0^{\circ}$ to $50^{\circ}$ were positive, while the judgment of angles between $60^{\circ}$ and $90^{\circ}$ produced negative errors. For the descending condition all errors were negative except at $0^{\circ}$. In summary, on the ascending trials the small angles were overestimated and the large angles were underestimated. On the descending trials there was a tendency to underestimate all angles. Also, the performance was more accurate on the ascending trials than on the descending.

TABLE 4

SUMMARY OF STATISTICAL SIGN TESTS OF THE PAIRS OF STATISTICS LISTED IN THE FIRST COLUMN

| Comparison | n* | r** | p |
|---|---|---|---|
| 1. Mean C.E.s for the Ascending and Descending Conditions | 10 | 1 | < .05 |
| 2. Mean S.D.s for the Ascending and Descending Conditions | 10 | 4 | -- |
| 3. Mean C.E.s for the First and Second Halves of Trials | 10 | 2 ½ | -- |
| 4. Mean S.D.s for the First and Second Halves of Trials | 10 | 1 | < .05 |
| 5. Mean C.E.s for the First and Second Halves of Trials for the Ascending Condition | 10 | 2 | -- |
| 6. Mean C.E.s for the First and Second Halves of Trials for the Descending Condition | 10 | 1 | < .05 |
| 7. Mean S.D.s for the First and Second Halves of Trials for the Ascending Condition | 10 | 3 | -- |
| 8. Mean S.D.s for the First and Second Halves of Trials for the Descending Condition | 10 | 2 | -- |

*n = the number of pairs (10 angular positions).

**r = the number of times the less frequent sign appeared.

The variable errors for the ascending and descending trials to the various positions are shown in columns 4 and 7 of Table 2 and in Figure 5. For both conditions, the variable errors were greatest near the midpoint of the scale, with a decrease in variability at the extremes. For the ascending trials the variability was least at 0° and greatest at 50°. For the descending trials the variability was least at 90° and greatest at 40°. There was no significant difference between the variability of the scores on the ascending and descending trials.

### C. Influence of Practice on the Accuracy of Estimating the Angular Positions

#### 1. Constant Errors

A statistical sign test of the 10 pairs of C. E. s for the first and second halves of the trials indicated that there was no

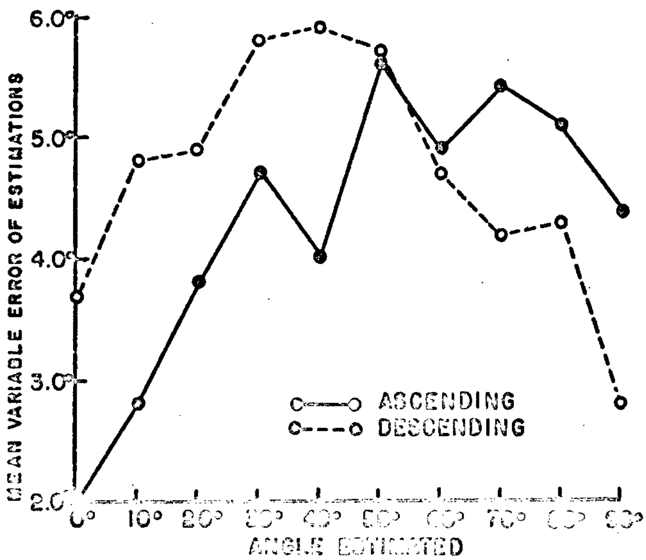


FIG. 5. MEAN STANDARD DEVIATIONS OF ESTIMATIONS FOR THE ASCENDING AND DESCENDING CONDITIONS OF ANGLES FROM 0° THROUGH 90° BY ARM MOVEMENTS IN IN THE HORIZONTAL PLANE.

significant decrease in errors with practice. From Figure 6 it may be seen that, with practice, the C.E.s were reduced at 7 of the 10 angles. The mean decrease in C.E. amounted to only 0.45°. There was an upward shift in the error curve toward the zero line but this resulted in an increase in error at 0°. As shown in Figure 6, the greatest changes in the errors occurred for the angles between 0° and 50°. The formal characteristics for the 2 curves are almost identical. Thus, with practice, the change was manifested as a shift in the entire error curve rather than by a general smoothing of the curve. (Compare Figure 6 and Figure 2).

2. Variable Errors

A comparison of the variable errors for the first and second halves of trials revealed that, with practice, there was a significant decrease in errors with the major changes occurring in

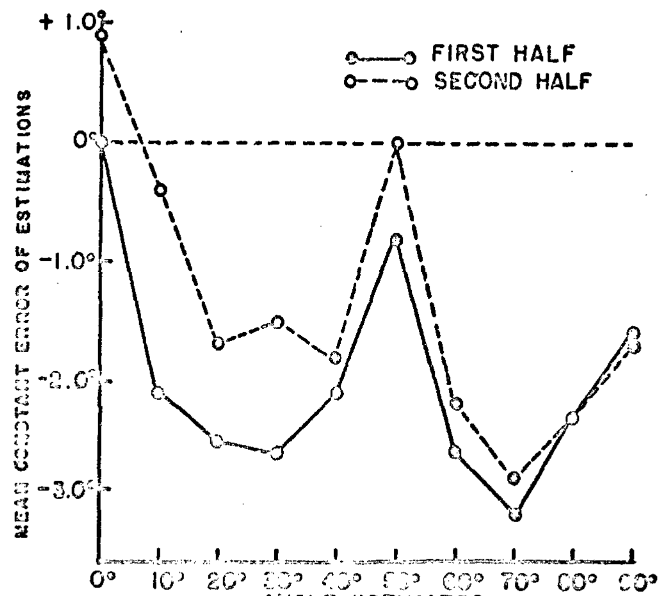


FIG. 6. MEAN CONSTANT ERRORS OF ESTIMATIONS FOR THE FIRST AND SECOND HALVES OF TRIALS OF ANGLES 0° THROUGH 90° BY ARM MOVEMENTS IN THE HORIZONTAL PLANE.

the region between $10^{o}$ and $40^{o}$. This decrease amounted to slightly less than one-half a standard deviation. A statistical sign test of the 10 pairs of S. D. s yielded a p of .02. As shown in Figure 7, there is little difference in the formal aspects of the variable error curves for the first and second halves of trials. Thus it was found that practice in this task resulted in a stabilization of the errors of estimate but no reduction in their size. Chapanis (1) obtained the same results in a study on the accuracy of knob setting.

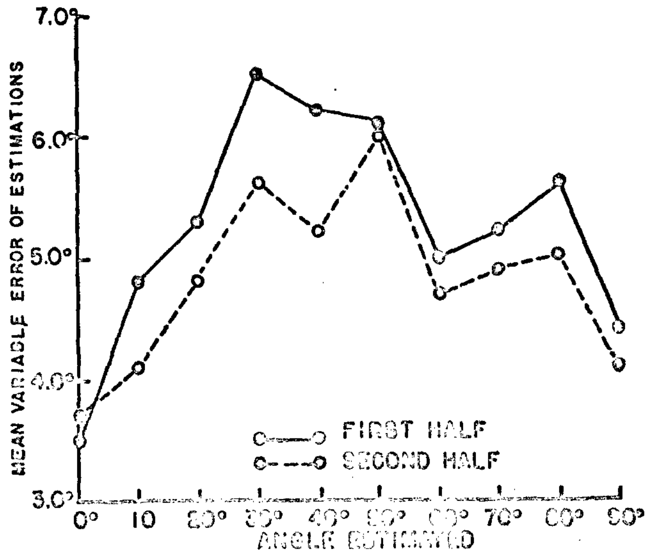


FIG. 7. MEAN VARIABLE ERRORS OF ESTIMATIONS FOR THE FIRST AND SECOND HALVES OF TRIALS OF ANGLES 0° THROUGH 90° BY ARM MOVEMENTS IN THE HORIZONTAL PLANE.

### 3. Ascending and Descending Trials

An examination of Figure 8 reveals that, with practice, there was a slight decrease in the accuracy of performances on the ascending trials. At 70° and 80° only are the C. E. s for the second half of trials smaller than those for the first half. The mean increase in error amounted to less than one-half of a degree. On the other hand, there is a decrease in error on the descending trials at all positions except 0°. This decrease amounted to approximately one degree. Analysis of these data by means of the statistical sign test demonstrated that the decrease in errors on the descending trials was significant at the 2% level of confidence. There was no significant change on the ascending trials.

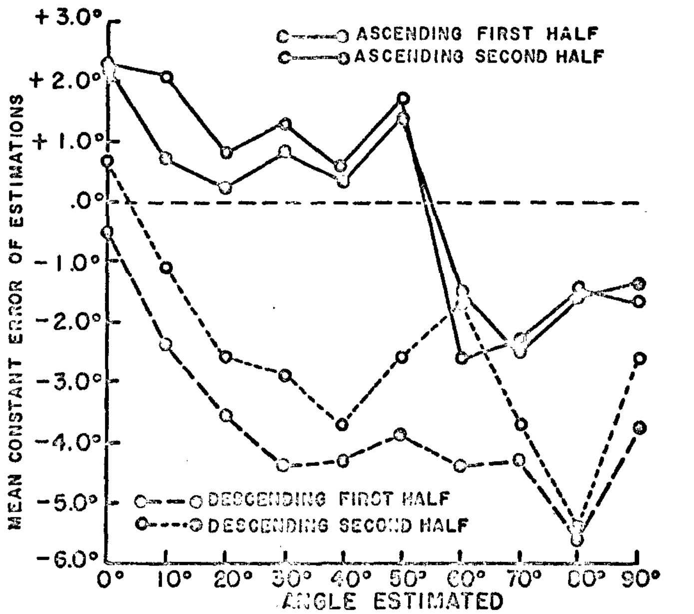


FIG. 8. MEAN CONSTANT ERRORS OF ESTIMATIONS FOR THE FIRST AND SECOND HALVES OF TRIALS FOR THE ASCENDING AND DESCENDING CONDITIONS OF ANGLES 0° THROUGH 90° BY ARM MOVEMENTS IN THE HORIZONTAL PLANE.

As shown in Figure 9, there was little decrease in the variability of performance on the ascending trials as compared to the descending trials. The variability of the ascending trials decreased by 0.1 S.D., while for the descending trials there was a decrease of 0.4 S.D. As shown by the sign test there was no statistically significant change in the variable errors for either condition, though for the descending condition there was a decrease in variability at 8 of the 10 angular positions.

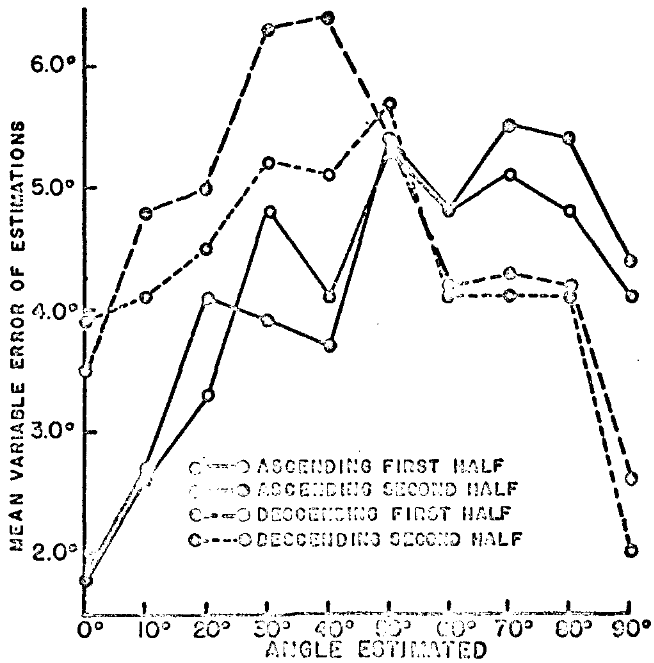


FIG. 9. MEAN STANDARD DEVIATIONS OF ESTIMATIONS FOR THE FIRST AND SECOND HALVES OF TRIALS FOR THE ASCENDING AND DESCENDING CONDITIONS OF ANGLES 0° THROUGH 90° BY ARM MOVEMENTS IN THE HORIZONTAL PLANE.

## IV. DISCUSSION

In general, it was found that the angles adjacent to the median plane (0°, 10°, 30°) were judged with the greatest degree of accuracy. Also, there was evidence of increased accuracy at 90°. The region of greatest inaccuracy was between 30° and 80°. These results are consistent with the reports made by several subjects who said that often in the middle region of the scale they were uncertain of the positions of their arms. These results tend to support the hypothesis that greater accuracy of angular judgments is obtained in the region where the greater number of kinesthetic cues are available. In other words, accuracy should improve as the limits of movement are approached and there is a consequent increase in muscle tension. This hypothesis will be tested in a forthcoming study on judgment of angular extent of movement as influenced by the region in which movement occurs. Extrapolating from the results of the present study, one would expect that accuracy in the discrimination of angular displacement would improve as the limits of arm movement are approached, with the greatest accuracy in the region adjacent to the median plane. When the movements of equal extent ($10^{\circ}$) to the various angular positions were considered, the error curves were found to be quite similar to those obtained when the angular displacements varied from angle to angle.

For the $10^{\circ}$ movements the angles between $0^{\circ}$ and $50^{\circ}$ were estimated most accurately on the descending trials and the angles between $60^{\circ}$ and $90^{\circ}$ were estimated most accurately on the ascending trials. This indicates that for movements of equal extent, adjustments for the positions near the median plane are most accurate when the control is moved toward $0^{\circ}$ and for the angles near the lateral plane adjustments are much more accurate when the movements are toward $90^{\circ}$. Thus, it appears that accuracy of angular estimations is greater when moving a control against an opposing force than when moving it with an aiding force. There is clear evidence that the judgments involving movement toward the larger angles are more accurate than those involving movement toward the smaller angles. The reason for the difference in accuracy for the two conditions may be traced to differences in the amount of tension necessary to hold the arm in the extreme positions. There is some evidence that, as the arm is moved from the low ($0^{\circ}$) or high ($90^{\circ}$) end of the scale, it is given momentum by the relaxation of the muscular tension necessary to hold the arm in the extreme position. This momentum, particularly when the arm was moved from the $90^{\circ}$ or $100^{\circ}$ positions, was reported by several subjects. The positive C. E. s for the angles from $0^{\circ}$ to $50^{\circ}$ for the ascending trials may be a result of a decrease in tension as one moves away from the frontal positions, and the greater negative C. E. s for the higher angles may result from stronger forces opposing movement to the lateral positions. The negative C. E. s for the descending trials may result from the decrease in tension as the arm is moved away from the lateral positions. It is noteworthy that the best subjects were affected as much by the direction of primary movement as were the least accurate subjects.

## V. SUMMARY AND CONCLUSIONS

The purpose of the present study was to determine, on the basis of the kinesthetic cues derived from movement of the arm, the relative accuracy with which angular positions from $0^{\circ}$ through $90^{\circ}$ in the horizontal plane could be located. The main results of the investigation are as follows:

1. Clear evidence of "perceptual anchoring" was obtained at the $0^{\circ}$ and $90^{\circ}$ positions. Accuracy was better at $0^{\circ}$ than at $90^{\circ}$. There was only slight evidence of increased accuracy near the midpoint of the scale.

2. The estimations of the angular positions were more accurate when the arm was moved toward the $90^{\circ}$ end of the scale than when it was moved toward the $0^{\circ}$ end. For the ascending condition the small angles were overestimated and the large angles were underestimated. This range effect was not evident in the data for the descending condition. There was a general tendency to underestimate all angles in the descending condition.

3. There are suggestions within the data that moving a control against an opposing force is better than moving one with an aiding force. This problem will be attacked in a future study on the effects of various types of loading on the accuracy of arm movements.

4. Even though the subjects received full information about the accuracy of their performance, the extensive practice did not result in a significant decrease in the constant errors. However, there was a significant decrease in the variable errors. Thus, it appears that practice in a task which involves the delayed recall of kinesthetic patterns of stimulation results in increasing stability of performance but little correction for the extent and direction of the mean errors.

It is believed that the series of studies originating with the present investigation will provide information to the human engineer concerning the influence of various types of control loading on errors of localization, and the role of kinesthetic feedback in the estimation of control positions.

## VI. RECOMMENDATIONS

Recommendations useful to the design engineer which follow from the results obtained in this investigation are: 1) a control can be most accurately located in the horizontal plane when it is positioned near the $0^{\circ}$ and $90^{\circ}$ positions (in front of the right shoulder or $90^{\circ}$ clockwise from this position); 2) a control can be more accurately positioned in the horizontal plane when it is moved toward $90^{\circ}$ than when it is moved toward $0^{\circ}$.

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